

TECTONICS AND COMPOSITION OF VENUS

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Abstract. The uncompressed density of Venus is a few percent less than the Earth. The high upper mantle temperature of Venus deepens the eclogite stability field and inserts a partial melt field. A thick basaltic crust is therefore likely. The anomalous density of Venus relative to the progression from Mercury to Mars may therefore have a tectonic rather than a cosmochemical explanation. There may be no need to invoke differences in composition or oxidization state.

The density of Venus is 1.2 to 1.9% less than that of the Earth after correcting for the difference in pressure [Ringwood and Anderson, 1977; Smith, 1979]. This has been attributed to differences in iron content [e.g., Kovach and Anderson, 1965], sulfur content [Lewis, 1972] or oxidization state of the mantle [Ringwood and Anderson, 1977]. Except for Venus there is apparently a decrease in iron content or an increase in oxidization state as one progresses away from the sun to Mercury to Mars. This trend is presumably related to the pressure and temperature gradient in the early solar nebulae.

I have recently argued [Anderson, 1979] that most of the original basaltic crust of the Earth subducted when the upper mantle temperatures cooled into the eclogite stability field. The density difference between basalt and eclogite is about 15%. Because of the high surface temperature on Venus the upper mantle temperatures are 200–400 K hotter in the outer 300 km or so than at equivalent depths on the Earth [Ringwood and Anderson, 1977; Toksöz et al., 1978].

Since the deep interior temperatures of the two planets are likely to be similar the near surface thermal gradient is controlled by the thickness, δ , of the conductive thermal boundary layer. This is related to the Rayleigh number, Ra , and the thickness, D , of the underlying convecting layer by

$$\delta \sim Ra^{-1/3} D$$

where

$$Ra = \frac{\alpha g \Delta T D^3}{\kappa \nu}$$

The Rayleigh number depends on the coefficient of thermal expansion, α , gravitational acceleration, g , temperature rise across the layer, ΔT , thermal diffusivity, κ , and kinematic viscosity, ν . The largest difference between Earth and Venus is the viscosity since this depends exponentially on temperature and pressure. The higher temperatures in the outer layer of Venus and the lower pressures throughout serve to decrease the average viscosity of the Venus

mantle by at least several orders of magnitude. The other parameters in the Rayleigh number are only weakly dependent on temperature or on the size of the planet. Because of the thinner boundary layer the near surface thermal gradient is steeper in Venus than the Earth. The net result is that the deep mantle adiabat is brought closer to the surface. This has interesting implications for the phase relations in the upper mantle and the evolution of the planet.

Schematic geotherms are shown in Figure 1 for surface temperatures appropriate for Earth and Venus. With the phase diagram shown, simplified from Wyllie [1971], the high temperature geotherm crosses the solidus at about 85 km. With Yoder's [1976] phase relations the eclogite field is entered at a depth of about 138 km. For Venus, the lower gravity and outer layer densities increase these depths by about 20%. Thus, we expect a surface layer of 100 to 170 km thickness on Venus composed of basalt and partial melt. This is in dramatic contrast to

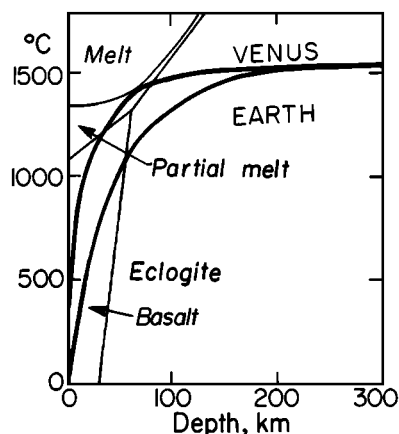


Fig. 1. Schematic geotherms for the Earth with different surface temperatures. Note that the eclogite stability field is deeper for the higher geotherms and that a partial melt field intervenes between the basalt crust and the rest of the upper mantle. Basaltic material in the eclogite field will probably sink through the upper mantle and be replaced by peridotite. Shallow subduction of basaltic crust leads to remelting in the case of Venus and the early Earth but conversion to eclogite and deep subduction for the present Earth. The depth scale is for an Earth-size planet with the colder geotherm and present crust and upper mantle densities. For Venus, with smaller g , higher temperatures and low density crust replacing part of the upper mantle the depths are increased by about 20%. The phase relations depend on the composition of the basalt. That shown is from Wyllie [1971]. An alternative composition [Yoder, 1976] places the eclogite boundary at 138 km for the upper geotherm.

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the Earth where the oceanic basalt layer is only 6 km thick and the average crustal thickness is 20 km. The tectonics on Venus is likely to be quite different from the thin plate-deep subduction style that we see on Earth.

A large amount of basalt has been produced by the Earth's mantle, but only a thin veneer is at the surface at any given time. There must therefore be a substantial amount of eclogite in the mantle which I have estimated to be the equivalent of about 450 km in thickness. If this were still at the surface as basalt the Earth would be 3% less dense. Correcting for the differences in temperature, surface gravity and mass and assuming that Venus is as well differentiated as the Earth but with a different basalt/eclogite ratio, the uncompressed density of Venus is calculated to be about 0.8 to 1.5% less than the Earth. We have assumed that the outer 100 to 170 km of Venus, which includes both basalt and partial melt, is 18% less dense than eclogite. Thus, depending on the composition of the basalt and the phase diagram chosen, most or all of the difference in density between Earth and Venus may be accounted for without invoking differences in composition or oxidation state. Venus may be closer to the Earth in composition than previously thought. It is possible that the present tectonic style on Venus is similar to that of the Earth in the Archean when temperatures and temperature gradients were higher.

Acknowledgments. I would like to thank J. V. Smith, W. Kaula and E. Stolper for helpful

comments on the original manuscript. This research was supported by NASA Contract No. NGL-05-002-069. Contribution No. 3291, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125.

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(Received September 17, 1979;
accepted November 27, 1979.)